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ECONOMIC IMPACT OF SALINITY INCREASE ON THE MISSOURI RIVER

Gene A. Ramsey

Federal Water Quality Administration
Kansas City, Missouri

October 1970

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I. INTRODUCTION

The concept of managing the water quality within an area or State has many facets. Various items and subjects must be investigated. Certain factors aid the manager in his efforts to maintain water quality. This brief study is about one tool available to managers--economics.

As water quality managers, we must be aware of the alternatives available to us and incremental costs associated with each alternative. Indeed, what is the economist's role in water quality control, if it is not in the pursuit of understanding through monetary analysis?

Until now, the Missouri River Basin (MRB) Regional Office of the Federal Water Quality Administration (FWQA) has not focused on the existing and future implications of increasing concentrations of salinity. To undertake a study of this magnitude for the entire basin, at this time, is beyond the limit of existing resources. However, an indication of the effects of increasing salinity can be obtained by examining a portion of the main stem of the Missouri River. What can have more of an impact on the entire MRB from a water quality aspect than an increase in total dissolved solids (TDS) and hardness as $CaCO_3$ in the Missouri River? For this study, salinity and TDS are synonymous.

The entire spectrum of increasing salt concentrations warrants some discussion. The MRB consists of vast land areas that have historically been marginal farming units. The Homestead Act of 1862 limited the size of the farm unit to 160 acres. This insured the agricultural entrepreneur to a fate of mere subsistence. This unit was not large

enough to enable the manager, using existing resources and farming techniques, to produce quantities of products that would enable him to prosper and raise his standard of living.

Had the vast prairies contained some other resource usable to man's needs of that day, the MRB undoubtedly would have become something other than an agricultural area. The MRB did not hold vast riches; as a result, its fate was determined by the basic forces of our economic system. The MRB has been and will continue to be an agricultural region. Recent trends and the outlook for the future indicate an intensification of land use never known before in the agricultural sector.

One farming practice contributes significantly to the situation of concern in this study--irrigation. The intensification of agricultural practices, namely irrigation, has resulted in increasing concentrations of salinity in the Missouri River via irrigation return flow. When land is irrigated, water is absorbed by the plants; some is lost through evaporation and transpiration, some runs off the land, some percolates down through the soil to the water table, and some finds its way back into the river. As the water moves over and through the soil, it takes up minerals into solution thereby increasing the concentration. These particles may be in the form of salt or minerals. Also, since the original amount of water applied is diminished and the amount of salt remains the same, concentration is increased. The irrigation operation results in a diminished amount of water that has an increased salt concentration.

The irrigation return flow water is the primary reason for the historical increase in salinity in the Missouri River. The return flow water contains minerals that are leached out of the soil and rocks. Ideally as irrigation continues year after year, an equilibrium called a salt balance is established, after which time consumptive use is the primary reason for increases in salinity. In many cases, sufficient water is not available or applied to leach out salts. The result is that soils hold constantly increasing volumes of salt which will eventually reduce production from these areas.

Irrigation projects are constantly being constructed as the intensification of land use progresses. The time has come for the MRB Regional Office of the FWQA to investigate and critically assess the water quality and broader environmental implications of irrigation practices. Increases in concentration of salinity have very significant effects on water uses, since once present in the Missouri River, they are present for years and may be a permanent source of water quality degradation.

The purpose of this general study is to "get a handle" or to attempt to measure the minimum effect of irrigation return flow damage through the increased concentration of salinity on the Basin. This is done by determining the effects of water quality degradation on users of the Missouri River for a water supply from Gavins Point to the confluence with the Mississippi River.

II. EFFECTS OF SALINITY ON WATER USES

The two effects of salinity considered in this study were the increasing amounts of TDS and hardness, as $CaCO_3$, and their effect on users of the Missouri River from Gavins Point, South Dakota, to St. Louis, Missouri. The increase in TDS results in additional costs for industries that must maintain a low level of salinity. Increases in hardness result in additional costs for municipalities striving to keep the level of hardness down in public water supplies.

The direct effects on uses that were measured on the Missouri River depended on the major consumptive or nonconsumptive uses. The consumptive uses considered were: (1) municipal, (2) industrial, (3) irrigation, and (4) livestock watering. The nonconsumptive uses considered were investigated and determined not to be affected significantly by the incremental increase of TDS or hardness. The consumptive uses were the primary factors that had damages assessed against them. A detailed discussion of the consumptive uses follows.

Municipal

The use of water for domestic purposes is generally considered to be the highest beneficial use. Standards for drinking water utilized by common carriers subject to the Federal Quarantine Regulations have been established by the United States Public Health Service.[1/]

Included in these standards are limits for certain inorganic materials which are mandatory in some cases and recommended, as is the situation of TDS and hardness, in other cases. The level of total hardness in a water supply is of primary interest in assessing water quality effects on

domestic use. A single criterion for maximum hardness is not recommended for public supplies by the U.S. Public Health Service. However, other publications do contain recommendations for desirable levels of hardness in public water supplies.[2/] Waters are normally classified in terms of degree of hardness ($CaCO_3$), as follows:[3/]

0 - 75 mg/l	soft
75 - 150 mg/l	moderately hard
150 - 300 mg/l	hard
300 and up	very hard

Using these criteria, raw water supplies on the Missouri River would be classified as "hard" and "very hard". Increases in the concentration of hardness can cause damages to municipal water users in several ways, such as increased plumbing costs, appliance and clothing wear and tear, and unpleasant physical characteristics. Two basic ways of assessing detrimental costs were used in evaluating municipal water use and are discussed in the sections following.

Water Softening - In communities where central water softening is practiced, higher levels of hardness in water increases the cost of treatment. Resulting increments of treatment costs can be related to anticipated increases in the hardness of water supply which constitutes softening evaluation. Private water softening was not evaluated, but is undoubtedly a substantial added cost to users.

Soap Consumption - Communities that do not have a central softening plant incur detrimental costs resulting from higher expenditures for soap and detergent. Such costs are normally greater than would be incurred in a central softening treatment plant.

Other methods of evaluation, which could be very significant, are scaling of metal water pipes and fittings or accelerated fabric wear. However, it was felt that the data available were not sufficient to support these methods of evaluation.

Industrial

The effect of water quality on industrial uses is difficult to generalize because of the varied purposes to which industry puts water. Industrial water use may be classified by purpose, as cooling, boiler feed, process, or general purpose.

When the raw water does not meet quality criteria for the various purposes described, industry can use two general types of treatment approaches: external or internal. External treatment, usually done by the city, is used when better quality water is required for nearly every purpose for which water is to be used. Such methods include water softening, chlorination, or clarification. Internal treatment is used to improve water quality for a particular purpose such as boiler feed water. In some cases, economic considerations lead to a combination of the two treatment approaches.

Of the four industrial water uses mentioned, boiler feed water used in power plants on the Missouri River was the only use evaluated. This was the most readily available and significant industrial use related to increases in total dissolved solids that could be evaluated by monetary means.

Boiler Feed Water - Quality of boiler feed water is a significant factor in the (1) rate of scale formation on heating surfaces, (2) degree of corrosion to the system, and (3) foaming. Three quality parameters--total dissolved solids, alkalinity, and hardness--are most important, their relative significance being dependent upon the system's operating temperature and pressure.

The study analysis included power plants on the Missouri River from Gavins Point to St. Louis (refer to Figure 1). Most power plant boilers in the study area operate in the 1,500-2,000 pounds of pressure per square inch (psi) range.

All boiler feed water in the study area needs some form of softening regardless of the water source. For units operating at pressure levels where boiler feed water softening by conventional means is appropriate, the detrimental costs due to salinity increases can be assessed in terms of increased treatment costs.

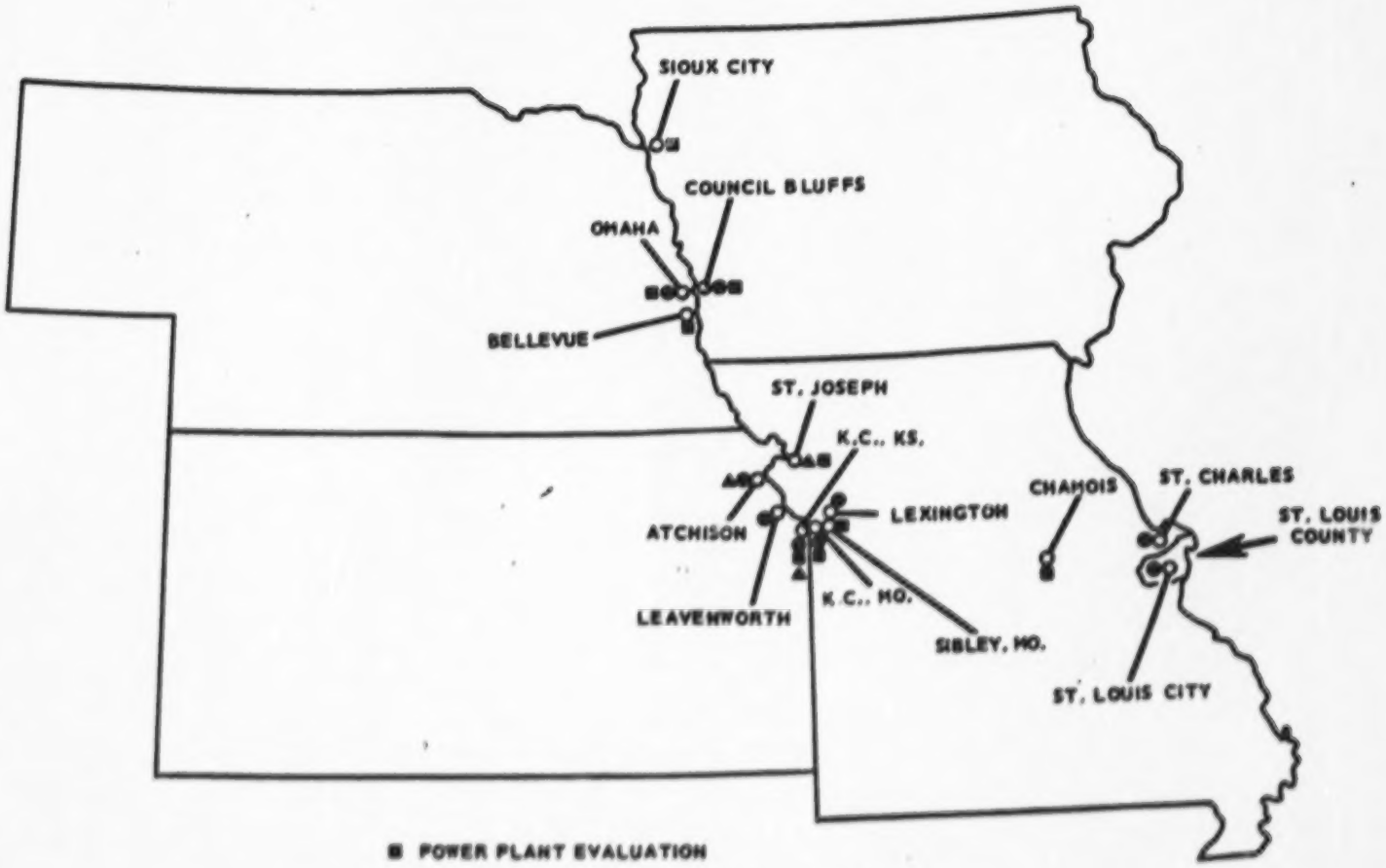

FIGURE 1 MUNICIPALITIES AND POWER PLANTS EVALUATED

In order to maintain a level of total dissolved solids in the boiler system that can be tolerated, some of the concentrated boiler water must be removed from the system. This process of solids removal by either continually or intermittently drawing off a portion of the circulating water is known as "blowdown". The quality of the boiler feed water introduced to the system in relation to the concentration that can be tolerated within the system determines the amount of blowdown required. The TDS and hardness tolerance level of boilers, in the pressure range in the study area, is very low. The "Water Quality Criteria" published by the Federal Water Pollution Control Administration specifies less than 1 mg/l for boiler feed water in the study area.[4/] Treatment costs associated with achieving this level of water quality determine the detrimental damages to the industrial sector.

Agricultural

Increases of salinity on agricultural uses were investigated in two categories: irrigation and livestock watering. Salinity increases reduce certain crop production when highly sensitive crops are irrigated. The potential for crop reduction due to increases in salinity was investigated. Since vegetables, fruits, and nuts are most susceptible to crop reduction resulting from TDS increases and production of these crops from irrigated Missouri River water is minor, damage to irrigated crop production in the study area as a whole is insignificant. Livestock watering was also considered, but data were not readily available to make an evaluation.

III. PRESENT AND FUTURE MINERAL QUALITY

In order to assess the economic impact associated with increases in TDS and hardness, it was necessary to establish a base water quality and to project future qualities. Long-range effects were to be assessed through the year 2020. The decision was made to use historical averages to determine base quality. Future changes could then be compared to the base quality in order to quantify the effect of anticipated development upon future water users.

Since the study area centers around the users of the Missouri River, TDS and hardness parameters for base and future water quality were needed. Available data, covering about 10 years of record, for TDS and hardness ($CaCO_3$) for surface water stations, were obtained.[5/] A relationship between TDS and hardness was identified from historical data. The amount of TDS in the Missouri River has been projected for the future years of 1980, 2000, and 2020 by the Missouri Basin Inter-Agency Committee.[6/]

The historical relationship between TDS and hardness was assumed to be applicable in the future. By using the historical relationship and the projected amount of TDS, a level of hardness was projected (see Table 1 and Figure 2). The projected levels of TDS assume no leaching. That is, consumptive use only is responsible for the increase in TDS and hardness. Therefore, the projected water quality values must be considered conservative in regard to future increases.

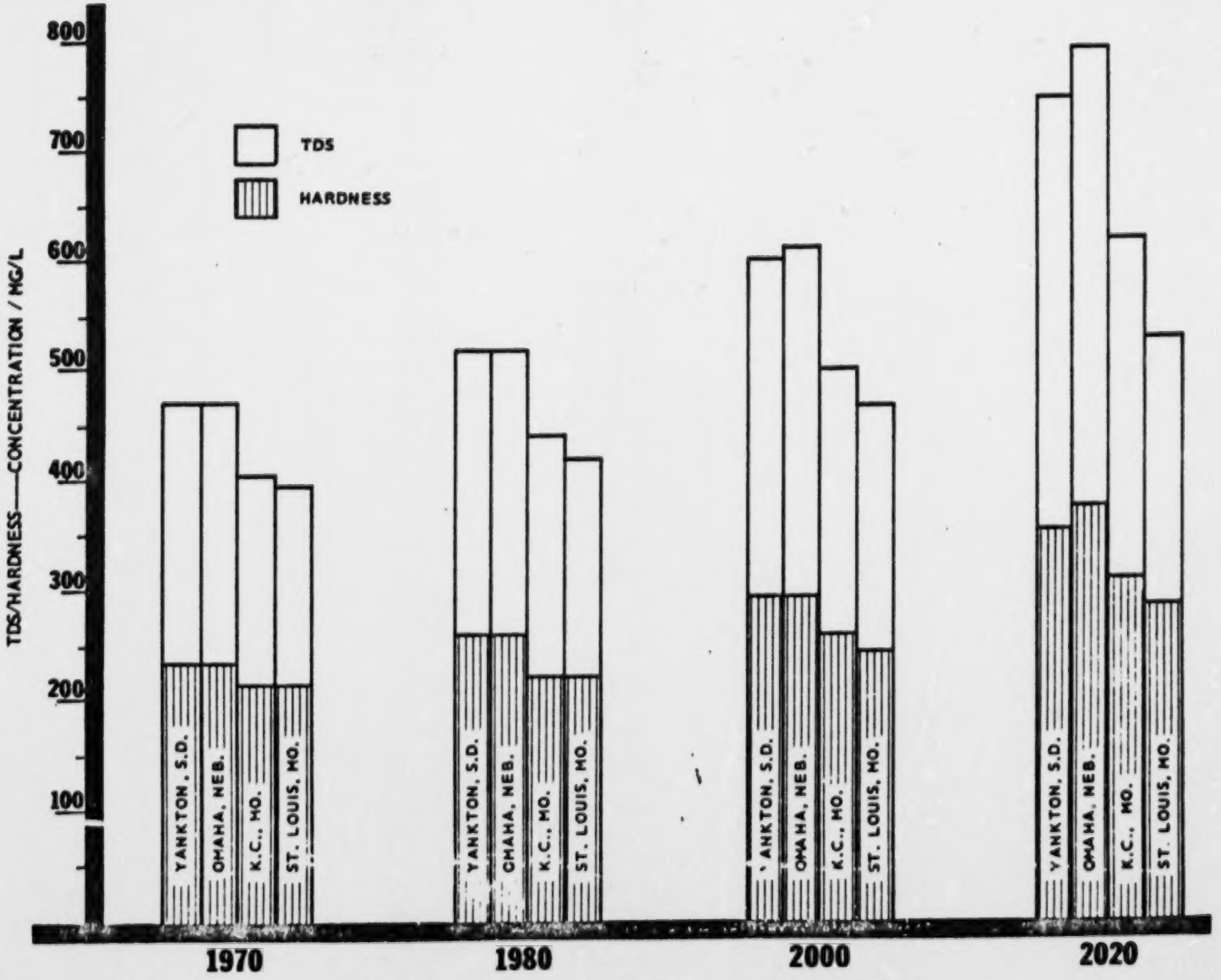

FIGURE 2 MINERAL QUALITY CHANGES ON THE MISSOURI RIVER

Table 1. Water Quality Values (mg/l) for Selected Stations on the Missouri River

Location	1970		1980		2000		2020	
	TDS[a]	Hardness[b]	TDS[a]	Hardness[b]	TDS[a]	Hardness[b]	TDS[a]	Hardness[a]
Missouri River @ Yankton,S.D.	470	235	520	260	600	295	750	355
Missouri River @ Omaha, Nebr.	470	235	520	260	610	295	790	375
Missouri River @ Kansas City, Mo.	400	210	440	225	500	255	620	305
Missouri River @ St.Louis,Mo.	390	210	420	225	460	245	530	280

a/ Missouri Basin Inter-Agency Committee - Water and Related Land Resources Development Appendix
b/ Hardness as $CaCO_3$

The TDS and hardness concentrations in the lower Missouri River are lower due to tributary flows which have lower concentration than the Missouri River. Also the rainfall in the area is sufficient for good agricultural production and supplemental irrigation is used only when necessary.

IV. DETRIMENTAL COST EVALUATION

Definition of Detrimental Cost

Detriments are user costs incurred when a specific water quality is used. A detrimental cost is the difference between the economic penalty associated with the use of two different levels of water quality. Therefore, it is based on similar economic conditions which permit the cost effect of water quality degradation to be isolated (refer to Figure 3).

It should be noted that if the raw water hardness remained at 250 mg/l, there would be an increase in the total cost from 1970 to 1980, but the increase is caused by changes in economic activity rather than water quality degradation. Although such a difference in economic conditions does represent an increased cost associated with water quality, it is not a detrimental cost as defined.

Methods of Detrimental Cost Evaluation

Users of Missouri River water are beginning to recognize that degradation of water quality has a direct economic penalty. Municipalities and industries are very sensitive to cost increases, particularly when there is no feasible alternative to the present source of water. Users must consider every way to keep costs down while using the best quality of water available. The methods used to determine costs follow.

Municipal

Municipal water use along the Missouri River is significant. Hardness, which is closely correlated with the amount of total dissolved solids,

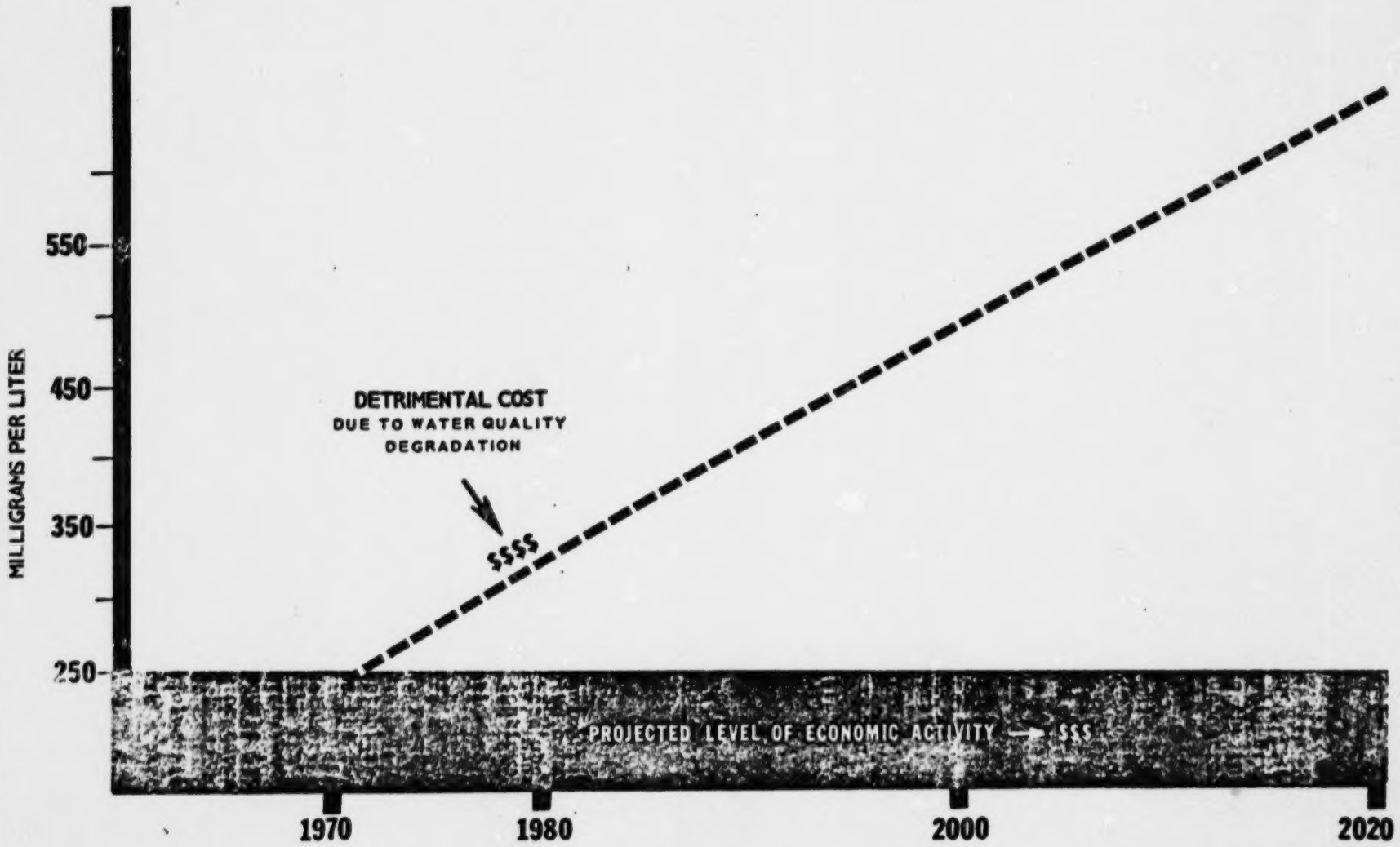

FIGURE 3 DETRIMENTAL DAMAGES RESULTING FROM WATER QUALITY DEGRADATION

causes problems for municipal users. Evaluation procedure could include several different methods: central softening, home softening, increased soap costs or plumbing costs associated with scaling. Each method was investigated as to the amount and quality of data available. The central softening and increased soap costs were determined to be the most reliable and were studied intensively. The home softening and plumbing cost approaches were found to be vague, with a wide variance in data. The two methods used for evaluation are discussed below.

Central Softening - Municipalities with softening facilities from Gavins Point (South Dakota) to St. Louis (Missouri), using the Missouri River as a source for municipal water, were evaluated (refer to Figure 1). Costs required to reduce raw water hardness were related to actual hardness reduction per million gallons treated. Most cities were very cooperative in the cost determination effort. Future water requirements for St. Louis City and County were reached by using future population projections and per capital water consumption rates.

Raw water hardness for the future was determined through the relationship between TDS and hardness that was identified in the historical records. The detriments for the target years were calculated using the following method:

Detrimental Costs = $QC\ (\Delta H_2 - \Delta H_1)$

Q = Annual volume of water treated - million gallons.

C = Unit operating cost of central softening expressed in dollars per million gallons per 100 mg/l hardness removed.

ΔH_1 = The difference in hardness between the 1970 influent quality and the same plant effluent quality.

ΔH_2 = The difference in hardness between a future target year quality and the plant effluent quality.

The cost of softening varied widely based on economies of scale, type of operation and chemical costs. Costs varied from $9.23 to $18.56 per million gallons per 100 mg/l of hardness removed. It was assumed that cities not softening now would not soften in the future which is certainly a conservative assumption.

Accepted Increased Hardness - The increased hardness results in an increase use of soap. The additional soap use associated with hardness was studied and identified by Eldridge.[7] An expenditure of $18.86 per household (adjusted to 1970 dollars) is experienced for each 100 mg/l increase in hardness. The number of households combined with the increase in hardness determined the detrimental cost for this alternative. Refer to Figure 1 for the cities that were evaluated by this method.

Industrial

The industrial sector evaluation involves boiler feed water only. Cooling water, industrial processing water, sanitary and miscellaneous water use are significant. Water treatment costs for some of these uses are high. However, time and resources dictated that the most expeditious method for industrial use classification be utilized.

Boiler feed water is in itself a broad category. It encompasses industries using boilers of any type. To focus on the industrial segment, it was decided to analyze the power plants using Missouri River water as a source within the study area (refer to Figure 1).

Most power plant boilers in the study area are in the 1,500-2,000 pounds per square inch range. These would be classified as sensitive to

changes in levels of TDS. Treatment costs associated with power plants are to reduce the level of TDS in the boiler feed water so it will not damage the boiler. These treatment costs vary from $.82 to $1.71 per 1,000 gallons of water used. Costs were assumed constant for the target years.

V. DETERMINATION OF DETRIMENTAL COSTS

Economic impacts from increased hardness and TDS on municipal and industrial users, respectively, are significant. Water use projections were made for municipal and industrial users on the Missouri River (refer to Figure 1). Projected water quality values were used at the intake point of the municipality or power plant. Calculations of detrimental costs are based on 1970 dollar value. The results are summarized in Table 2 and Figure 4.

Table 2. Summary of Detrimental Costs in Missouri River Study Area--Area From Gavins Point to St. Louis

	Target Years		
	1980	2000	2020
	($1,000 Annually)		
Municipal	562.3	1,790.8	5,433.6
Industrial	54.9	349.9	1,183.9
Total	617.2	2,140.7	6,617.5

The results of the analysis indicate that $617,000 in detrimental costs accrued to municipal and industrial users in 1980. The projected total for the year 2000 will be $2.1 million. The projected total for the year 2020 will be $6.6 million. The majority of the detrimental costs occur as a penalty to municipalities.

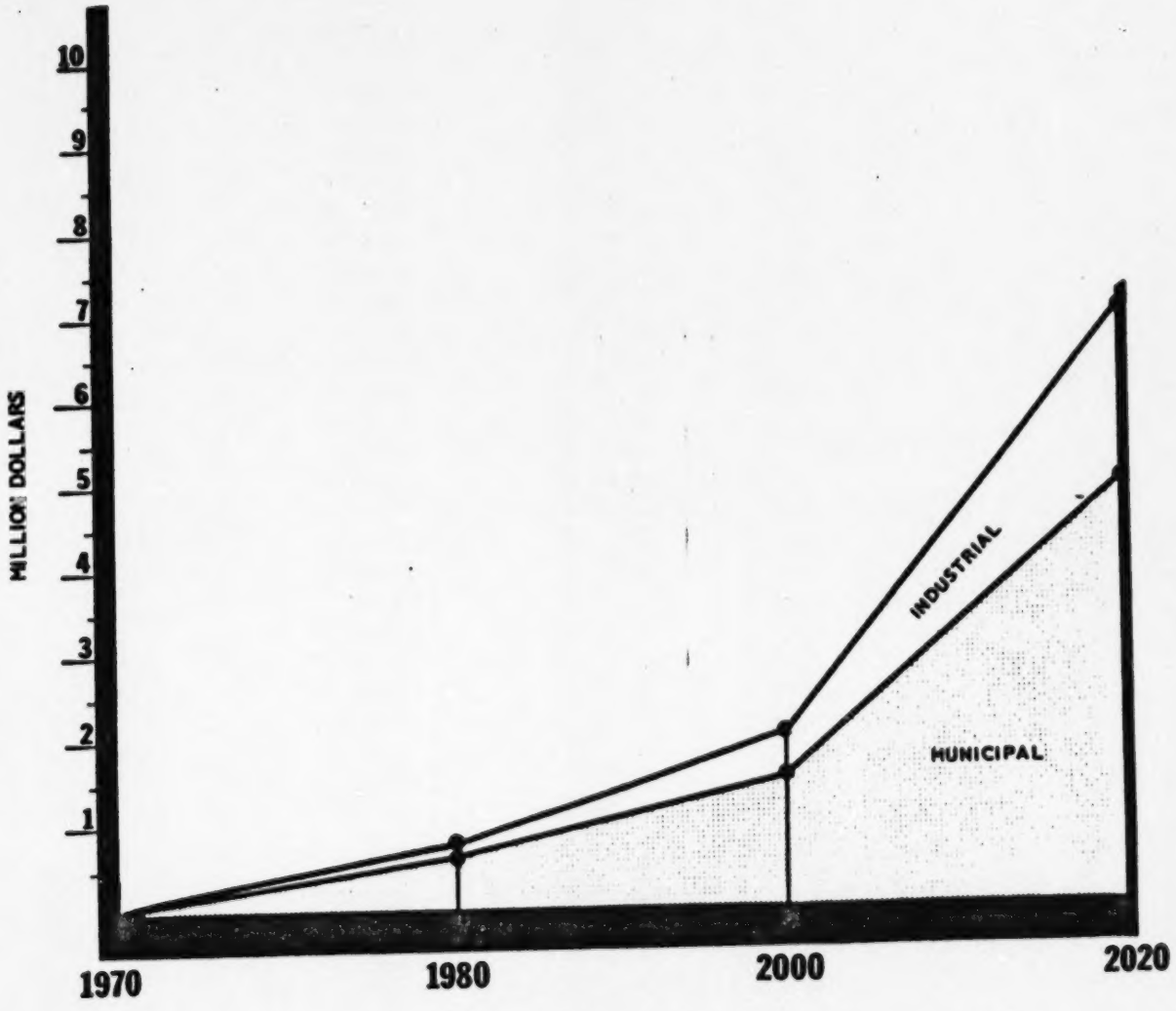

FIGURE 4 DETERIMENTAL COSTS IN THE MISSOURI RIVER STUDY AREA

VI. CONCLUSIONS

The determination of detrimental costs was done for municipalities and power plants on the Missouri River. The industrial sector was not evaluated as to cost occurring to industries from increasing TDS other than power plants. Food processing industries, manufacturing industries, home water softening, pipe scaling and others that are sensitive to increase in TDS or hardness were not evaluated. Also, the main stem of the Missouri River from Gavins Point to St. Louis only was considered. The remainder of the basin was ignored.

In other words, the detrimental costs for the target years are the absolute minimum costs associated with increasing TDS and hardness, even at the $617,000 level by 1980, $2.1 million by 2000, and $6.6 million by 2020. A study area of any less would not be justified, unless connected with a particular irrigation project. Also, the detrimental costs for the target years are in addition to the 1970 base treatment cost for municipalities and industries of almost $2 million.

When the detrimental costs are examined in the proper perspective, they reveal the significant impact water quality degradation has on the Missouri River Basin as a result of increasing TDS and hardness due to irrigation return flow. It is time this water quality degradation is recognized and steps taken to prevent its actual occurrence.

VII. RECOMMENDATIONS

A full scale evaluation of TDS and hardness increases in the Missouri River and possibly the entire basin should be done. The greatest concentration of people and economic activity in the basin is centered around the main stem of the Missouri River. Therefore, an intense study of the lower portion, from Gavins Point to St. Louis, of the Missouri River would yield the greatest results.

The detrimental costs (for municipal and power plant boiler feed water) determined in this study are a portion of the direct costs. All the direct costs (for agriculture, industrial processing, cooling water and households) resulting from increases in TDS and hardness have not been evaluated. Industries using cooling, processing or boiler feed water were not included in the study. There are many industries along the Missouri River that could be included in this category. The municipal cost evaluation could include an assessment of the use of home water softening units as opposed to a central softening plant.

The indirect detrimental costs accruing to agriculture, industry, eating and drinking, retail trade and services were not considered in this study. These would include numerous indirect effects which are brought about by the interdependence of economic activities. This secondary, or indirect effect, continues in a domino-like sequence until all such independent relationships have been exhausted. These added costs of production induce indirect costs through a misallocation of resources (expenditures for treatment versus expenditures for productive purposes) representing a

loss to the optimum regional economic output. This misallocation of resources can be measured through the use of input-output analysis. This type analysis establishes the linkages between sectors of the economy and would allow indirect detrimental costs to be determined.

An input-output study of the lower portion of the main stem would yield significant benefits for the Regional Office, one of which would be the measurement of indirect detrimental costs resulting from increases in TDS and hardness. The States of Nebraska and Kansas have completed input-output models for their respective states. If these studies could be utilized, a significant start would be underway.

This analysis would also lend itself in determining mitigation damages against the Bureau of Reclamation. The detrimental costs could be determined and if TDS values were reduced as a result of reservoir management for water quality control, then the damages could also be reduced. This method would result in greater concern for quality water management below Bureau projects.

BIBLIOGRAPHY

1. U.S. Department of Health, Education and Welfare, Public Health Service, "Drinking Water Standards, 1962," U.S. Government Printing Office, Washington, D.C., 1962.

2. U.S. Department of the Interior, Federal Water Pollution Control Administration, "Water Quality Criteria," U.S. Government Printing Office, Washington, D.C., April 1, 1968.

3. Sawyer, Clair N., "Chemistry for Sanitary Engineers," McGraw-Hill Book Company, New York, 1960.

4. U.S. Department of the Interior, Federal Water Pollution Control Administration, "Water Quality Criteria," U.S. Government Printing Office, Washington, D.C., April 1, 1968.

5. U.S. Department of the Interior, Federal Water Pollution Control Administration, "Storage and Retrieval System," Washington, D.C., 1970.

6. Missouri Basin Inter-Agency Committee, "Water and Related Land Resources Development Appendix," Washington, D.C., 1970.

7. Eldridge, Edward F., U.S. Department of Health, Education and Welfare, "Characteristics and Effects of Return Irrigation Water," Public Health Service, Portland, Oregon, May 1, 1960.